Senior Service College FELLOWSHIP PROJECT

ALTERNATIVE ENERGY AND PROPULSION POWER FOR TODAY'S US MILITARY

BY

COLONEL GREGORY M. FIELDS
United States Army

USAWC CLASS OF 2009

This SSCFP is submitted in partial fulfillment of the requirements imposed on Senior Service College Fellows. The views expressed in this student academic research paper are those of the author and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the U.S. Government.

U.S. Army War College, Carlisle Barracks, PA 17013-5050

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 05-05-2009	**2. REPORT TYPE** Civilian Research Paper	**3. DATES COVERED** *(From - To)* 13 Aug 08 – 5 May 09

4. TITLE AND SUBTITLE

Alternative Energy and Propulsion Power for Today’s US Military

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

COL Gregory M. Fields

5d. PROJECT NUMBER

R0578

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The Institute of Advanced Technology
The University of Texas at Austin
3925 West Braker Lane, Suite 400
Austin, Texas 78759-5316

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Mr. Robert Riffle
The Institute of Advanced Technology
The University of Texas at Austin
3925 West Braker Lane, Suite 400
Austin, Texas 78759-5316

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION A: UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This intent of this paper is to provide a cogent argument for why the US military needs to aggressively pursue alternate forms of energy and propulsion power technologies that will dramatically reduce or eliminate the current dependence on foreign petroleum. The research and analysis centered on the premise that the US military, for decades, has been severely constrained by the burden of traditional fossil-fuel-using technologies, which greatly lessens its ability to conduct operational missions anywhere in the world. This premise is supported by factual data that is elaborated on extensively in the paper.

A number of federal government agencies were consulted, and numerous documented sources from industry and academia were used in the research for this paper. The technologies discovered among these entities were evaluated and determined worthwhile for investment by the US military, particularly the Army.

Although many technologies were reviewed, this paper only focused on the technologies that are viewed as having the greatest potential for military application. In the end, this paper recommends to senior military leadership viable technologies that are worth pursuing at this time as well as one that needs aggressive research initiated now, given its potential for the future.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Robert D. Riffle, Program Adviser
UNCLASSIFED	UNCLASSIFED	UNCLASSIFED	UNLIMITED	60	**19b. TELEPHONE NUMBER** *(include area code)* 512-232-4560

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

USAWC CIVILIAN RESEARCH PAPER

ALTERNATIVE ENERGY AND PROPULSION POWER FOR TODAY'S US MILITARY

by

Colonel Gregory M. Fields
United States Army

Mr. Robert Riffle
Program Adviser
The University of Texas at Austin

US Army War College
CARLISLE BARRACKS, PENNSYLVANIA 17013

ABSTRACT

AUTHOR: COL Gregory M. Fields

TITLE: Alternative Energy and Propulsion Power for Today's US Military

FORMAT: Civilian Research Project

DATE: 30 April 2009 WORDS: 11,949 PAGES: 60

CLASSIFICATION: Unclassified

This intent of this paper is to provide a cogent argument for why the US military needs to aggressively pursue alternate forms of energy and propulsion power technologies that will dramatically reduce or eliminate the current dependence on foreign petroleum. The research and analysis centered on the premise that the US military, for decades, has been severely constrained by the burden of traditional fossil-fuel-using technologies, which greatly lessens its ability to conduct operational missions anywhere in the world. This premise is supported by factual data that is elaborated on extensively in the paper.

A number of federal government agencies were consulted, and numerous documented sources from industry and academia were used in the research for this paper. The technologies discovered among these entities were evaluated and determined worthwhile for investment by the US military, particularly the Army.

Although many technologies were reviewed, this paper only focused on the technologies that are viewed as having the greatest potential for military application. In the end, this paper recommends to senior military leadership viable technologies that are worth pursuing at this time as well as one that needs aggressive research initiated now, given its potential for the future.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

This paper is the result of the author’s Army War College Fellowship at the Institute for Advanced Technology (IAT) at The University of Texas at Austin. I would like to thank Mr. Bob Riffle, COL Jeff Caton, the IAT editing staff, and the IAT resource staff for their guidance and invaluable assistance. I also would like to thank engineers and scientists at the U.S. Army Tank Automotive Research, Development and Engineering Center’s National Automotive Center, the Environmental Protection Agency, the Department of Energy, and the Defense Advanced Research Projects Agency for their insight, cooperation, and assistance. Finally, I would like to thank my wife, daughter, and son for having the patience, understanding, and providing moral support as I conducted this research.

LIST OF ILLUSTRATIONS

ALTERNATIVE ENERGY AND PROPULSION POWER FOR TODAY'S US MILITARY

Introduction

The US military has the most sophisticated weapon systems in the world but they are fueled and mechanically powered by old technologies. Outdated internal combustion mechanical engine technologies and petroleum based fuels have rendered an otherwise free nation subject to a crippling dependence on other countries, giving these foreign nations power over the United States. Some could argue that historically our military, which is dependent on mechanical internal combustion engine technologies, has not conducted any major operational campaign without the use of other nations' fuel resources. Currently our capitalistic edge is the only thing that gives us a true advantage over other nations' armies. As other nations become more equal in economic power, so will technological advances be made in their armed forces. A country equal or near equal in economic and military power but considerably less depend on fossil-fuel-based technologies would pose a major threat to our nation. As long as there is a dependence on outdated technologies and external US sources to fuel our military, America will never have a military that can operate anywhere in the world and truly be self-sufficient and independent.

Americans seem to have a greater interest in the matter of energy independence today than at any other time in recent history, because it has become such a challenge just to fill their gas tanks and heat and cool their homes, not to mention the impact on necessities such as food. These related challenges are compounded for the military, given its need to essentially be self-sufficient in its global operational mission. Energy independence will be extremely difficult for our new president to ignore, given how petroleum and internal combustion technologies have affected every relevant aspect of Americans' lives in a negative way. We need to take advantage of this re-emergent, heightened interest in energy independence—a matter that has continuously plagued our nation, and our military, for decades—and pursue the opportunity in hopes of gaining something positive out of it that would greatly benefit our country in most profound ways. Other nations are ahead of the United States on efforts to break these bonds of dependence on fossil fuel and related technologies. There is no better time than now for the US military to embark on similar beneficial endeavors.

The year 2008 finished with the world economy being at perhaps its worst in modern history. This was an international crisis that had a devastating effect on major world markets—with the United States, arguably, being impacted the worst. Every commodity sector took a hit including, for the first time in a baby boomer's lifetime, the petroleum oil market. For at least three decades, foreign oil companies and major US oil companies enjoyed record profits, which seemed to rally with no end in sight until late summer of 2008. In fall 2008, fuel prices began to fall significantly—to the lowest in over five years, which has never happened before. Americans seem to have fallen back into a sense of comfort, thinking that these historically low fuel prices will remain at these levels for the foreseeable future. Soon, the oil market will rebound and American consumers will be stuck with high fuel prices once again, simply because we are so dependent on foreign oil. We are at a unique time in history where we have the technological wherewithal to redirect our energy destiny to conform to our energy needs.

Background

Given the make-up and mission of the US military, it is without question the largest oil-using organization of its kind in the world. More than half of the defense department's fuel budget is spent on fueling the US Air Force. The Navy consumes about one-third of defense oil resources, and the Army uses around 12%. Twenty-five percent (25%) of military energy is used to power and heat buildings and facilities—the remaining 75% is consumed for mobility purposes.[1]

Of the total US government liquid fuel use, about 97% is consumed by the Department of Defense (DoD), making that agency the world's single largest fuel-burning entity. According to data supplied by the Defense Energy Support Center (DESC), the inter-service breakdown for fuel use is as follows:

- Department of the Air Force, 53%,
- Department of the Navy (including Marine Corps), 32%.
- Department of the Army, 12%.

According to the US Defense Energy Support Center (DESC) Fact Book 2004, in Fiscal Year (FY) 2004, US military fuel consumption increased to 144 million barrels. This is about 40 million barrels more than the average peacetime military usage.[2] It is important to note that peak years for oil procurements were 2002, 2003, and 2004, which are from the US military's existing operations in Operation Enduring Freedom (OEF) and the build up to and during the early stages of Operation Iraqi Freedom (OIF). According to DESC Fact Books in subsequent fiscal years, petroleum procurements were reduced beginning in FY 2005 to present, but fuel consumption remained considerably high.[3] The DoD spent $8.2 billion on energy in FY 2004.[4] This was a peak year due to two major simultaneous war efforts—OEF and OIF, with OIF beginning its second year of operations. In FY 2005, DESC estimated that it would buy about 128 million barrels of fuel at a cost of $8.5 billion. Jet fuel constitutes nearly 70 percent of DoD’s petroleum product purchases.[5] The actual purchase ended up being over 132 million barrels.

Here are some interesting historical observations to further solidify the point:

- The Army calculated that it would burn 40 million gallons of fuel in three weeks of combat in Iraq, which is an amount equivalent to the gasoline consumed by all Allied armies combined during the four years of World War I.[6]
- In May 2005 issue of The Atlantic Monthly, Robert Bryce gives another example; “The Third Army (of General Patton) had about 400,000 men and used about 400,000 gallons of gasoline a day. Today the Pentagon has about a third that number of troops in Iraq yet they use more than four times as much fuel.”[7]
- According to the Defense Logistic Agency, in November 2005 more than 2.1 billion gallons of fuel have been used since October 2001 in support of Operation Enduring Freedom.[8]

Figure 1[9], shows the proportions of DoD energy consumed by fuel type in FY06. [10]

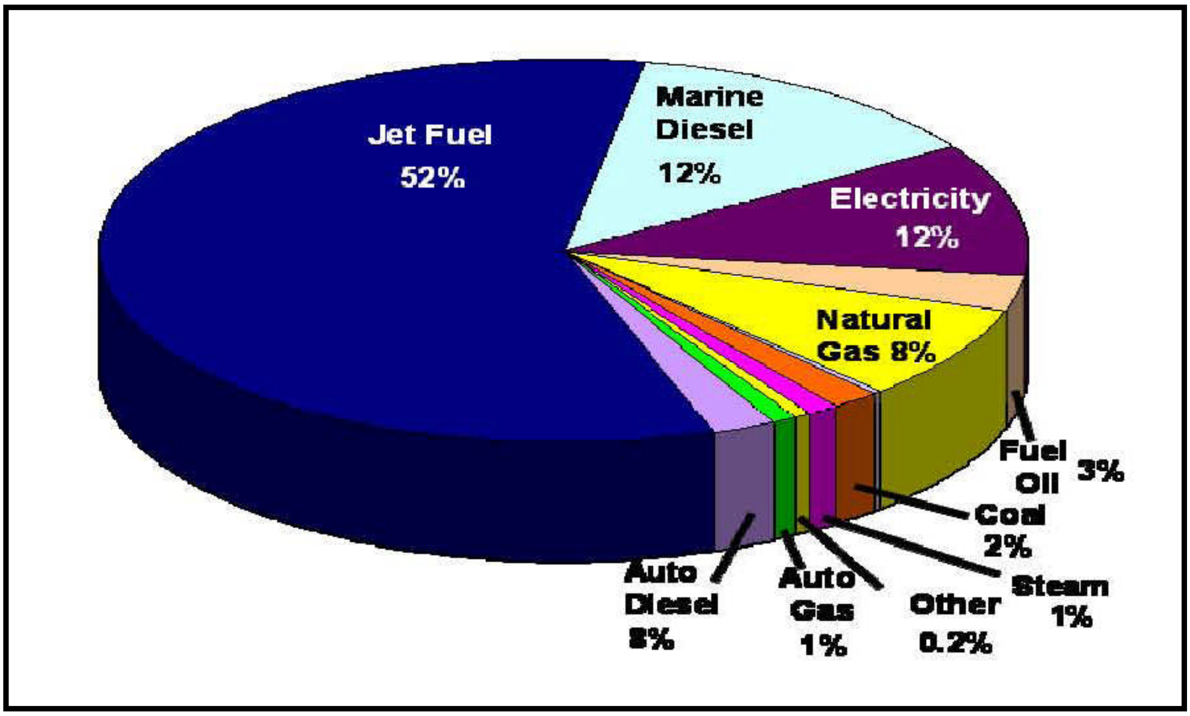

Figure 1. DoD energy consumption by type of fuel.

According to the DESC's more recent FY 2007 Fact Book, 132.5 million barrels of petroleum were purchased for DoD at a cost of $12 billion, with the Army's portion being $2 billion. Statistical trends from DESC Fact Books show that petroleum usage for the operational military engaged in war activities has progressive increased since 2002. Although there has been a decrease beginning in 2005, petroleum consumption is still significantly above pre-2002 levels, where it is believed they will continue to remain for some time.

As the statistics and chronology show, DoD consumes more petroleum fuels than any other entity of comparative size due to the nature of its massive complex mission, and actions must be taken to reduce its grip on fossil fuels.

Further Defining the Problem

In 2006 testimony before the US Congress, a DoD representative stated that "mobility" type fuel—that used in aircraft, ships, and vehicles—accounts for almost 75% of total DoD energy consumption. Thus, fuel used to heat and power buildings and facilities accounts for about 25% of DoD energy usage. In terms of fuel types, jet fuel accounts for 58% of mobility fuel. (Jet fuel is used in aircraft and non-aircraft platforms, such as tanks, other ground vehicles, and power generators.) The balance of energy usage, 17%, comes from marine diesel, electricity, fuel oil, gasoline, and other sources, such as nuclear, wind, and solar, which are primarily used for base/installation operations and not tactical units. It is important to note that DoD is one of the largest single generators and users of renewable power in the United States, and it uses the most various types as well.[11]

It is certainly understandable why the US military uses such a great deal of fuel for mobility to conduct tactical operations. The Air Force is focused on airlift and platforms that can deliver strike packages from the air. The Navy and Marine Corps are focused on sealift and sea-delivered strike packages. The Army has a mission focused on maneuvering and fighting, seizing and holding terrain. This is a simplification of the respective service missions, which are quite broad, complex, and very much interrelated, but it illustrates the military's insatiable requirement for petroleum energy and further supports the need to explore alternative energy to satisfy the operational necessities of our military.[12]

Real Illustrations of the Problem

Warfighting commanders in the field are requesting alternatives to petroleum based energy. In 2006, the Marine Corps commanding general in Anbar Province, Iraq, placed a top-priority request for renewable (wind and solar) energy systems to power fixed bases and installations in his area of responsibility. Currently, US military operations in Anbar are dependent on long logistics lines, stretching back into Kuwait, over which large volumes of fuel must be hauled just to power generators for base lighting and computer operation. The drivers, trucks, and fuel are all subject to attack along the lines of travel. The Marine Corps general wanted to reduce the requirement for liquid fuel supplies, and has requested systems that are based on photovoltaic power generation supplemented by easily installed wind systems coupled to battery storage cells. It is important to note that these systems are in production, have already been deployed elsewhere in the world, and are available.[13] It is unclear if this commander's renewable energy request was ever fulfilled.

The US Army is replacing the High Mobility Multipurpose Wheeled Vehicle (HMMWV), and the alternatives may not yield better fuel efficiency. One of the key complaints about this versatile battlefield vehicle is that it consumes too much fuel. The HMMWV gets as few as 4 miles per gallon in city driving and 8 miles per gallon on the highway, and a great deal worse over cross-country terrain. The Army wants to see a HMMWV replacement that weighs 30–40% less and that uses proportionately less fuel; however, this remains to be seen.[14]

Since the US Air Force uses the most petroleum based fuels, it is leading the way in alternative fuel research. The Air Force is qualifying new types of fuel derived from both natural gas and coal. On September 19, 2006, a B-52 bomber flew with one engine mount using a newly produced liquid fuel derived entirely from natural gas. Due to the nature of the manufacturing process, the fuel contains virtually no sulfur and hardly any heavy metals, which is good for prolonging engine longevity, when compared to jet fuel derived from refined petroleum. In ground-based testing, the engines that burned this new type of fuel did not experience any measurable loss of performance and required less maintenance. Another virtue of this synthetic fuel is that it has a storage life that is ten to one hundred times longer than petroleum-derived fuels.[15] One final note: the Air Force is still constrained to using foreign petroleum in locations outside the United States. All services could benefit from this research effort if this synthetic fuel could be used in ground tactical vehicles, helicopters, and other fuel using support systems just as the current petroleum-based jet fuels are used today. This of course assumes that this synthetic fuel is easily obtainable and producible.

With the US Navy being the second largest DoD user of petroleum-based fuels, it is experimenting with ship designs and construction techniques that are anticipated to produce vessels that are ten to hundred times more efficient than in years past. Naval architects and ship designers are working to build performance into ship systems, anticipating unrelenting higher oil costs in the future, and a continued dependence on foreign oil. Some novel ideas envision certain future classes of Navy ships using masts and sails, with the sails and the exterior of the hulls coated with photovoltaic cells, all with the goal of reducing the requirement for liquid mobility fuel.[16] The Navy continues to conduct analysis-of-alternatives studies, but it could not be confirmed whether the Navy had mounted a strong effort to pursue real technological alternatives.

Worth mentioning is operations ashore; both the Navy and the Air Force are among the largest generators and consumers of “green energy”, almost all of it derived from windmills.[17] This helps to reduce the burden of procuring petroleum fuel for base operations and allows them to focus resources toward the petroleum needs of their mobile tactical and operational systems.

With more focus by Congress and senior Pentagon leaders, green energy technological initiatives would better serve all branches of the military, especially in overseas, remote areas. Again, this would at least free up fossil fuels to be used in military systems now, thus reducing the need to buy more foreign fuel.

According to US Representative Roscoe G. Bartlett, the US military is "doing more than anyone else in the government or around the country" to address a future in which energy supplies will be scarce and expensive. Representative Bartlett adds, "I don't think the country as a whole has any perception of the danger" of America's reliance on foreign oil.[18] Our nation would benefit enormously if the US military were provided the resources needed to solve this fossil-fuel dependence problem. No one entity has a bigger reason for solving the foreign energy dependence problem than our military. Such a solution would significantly strengthen our nation's security posture and benefit America as a whole.

Pentagon Leader Desires to Change Course

On May 2, 2006, the Defense Science Board (DSB), at the direction of the Under Secretary of Defense for Acquisition and Logistics conducted another review of DoD's energy strategy. This was essentially an update or review of what had transpired since the DSB's 2001 report entitled "Improving Fuel Efficiency of Weapons Platform." The under secretary cited significant risks to both our nation and our military forces, and he challenged the Task Force to find opportunities to reduce DoD's energy demand, identify institutional obstacles to their implementation, and assess their potential commercial and security benefits to the nation.[19]

Based on its study and deliberations, the DSB concluded that DoD faces an unnecessarily high and growing battlespace fuel challenge that

- compromises operational capability and mission success;
- requires an excessive support force structure at the expense of operational forces;
- creates more risk for support operations than necessary; and
- increases life-cycle operations and support costs.

Some of the DSB's more pertinent findings and recommendations follow.

Finding: There are technologies available now to make DoD systems more energy efficient, but they seem to be undervalued, slowing their implementation and resulting in inadequate future science and technology investments.

The DSB heard over a hundred presentations on technologies that addressed all categories of end use and covered the full range of maturity from basic research to ready-to-implement. Many appear quite promising, but DoD lacks accepted tools to value their operational and economic benefits, such as the Hybrid Electric Vehicle Experimentation and Assessment program, which evaluates the potential military application of hybrid vehicle technologies.[20] As a result, cost effective technologies are not adopted, science and technology programs significantly under-invest in efficiency relative to its potential value, and competitive prototyping to accelerate deployment of efficiency technologies is not done.[21]

Recommendation: Accelerate efforts to implement energy efficiency key performance parameters (KPPs) and use the fully burdened cost of fuel (FBCF) to inform all acquisition trades and analyses about their energy consequences, as recommended by the 2001 Task Force.

The DSB recognizes two key initiatives recently launched by the Joint Staff (JS) and Office of the Secretary of Defense (OSD) to implement the 2001 Task Force recommendations:[22]

- An August 17, 2006, Vice Chairman of the Joint Chiefs of Staff (VCJCS) memorandum (JROCM 161-06) endorsing a Joint Requirements Oversight Council (JROC) decision to establish an energy efficiency KPP.
- An April 10, 2007 USD(AT&L) memorandum establishing department policy to use the FBCF for all acquisition trade analyses.

While these are essential reforms, little progress has been made in implementing them, and little action has been taken to develop the necessary analytical capabilities to establish meaningful values for either initiative. The DSB recommended that the DoD accelerate the following tasks:[23]

- build fuel logistics into campaign analyses and other analytical models and simulations to inform the requirements process of the operational, force structure, and cost consequences of varying battlespace fuel demand;
- establish outcome-based energy KPPs; and
- use FBCF as a factor in all analyses of alternatives (AoAs)/evaluations of alternatives (EoAs) and throughout all acquisition trades.

The DSB also recommended that these apply to all actions that create demand for energy, including "black" programs and nondevelopmental systems used at forward operating locations.[24]

It appears that neither the energy efficiency KPP nor the FBCF have been put in policy or active practice. These are key recommendations that should be implemented.

Just as the net ready KPP was directed several years ago for tactical communication systems, which required materiel developers to address communication capabilities to support joint networking, a directed energy efficiency KPP would require materiel developers to address fuel efficiency by way of alternative energy technologies during the acquisition of tactical mobility and stationary support systems. An FBCF mandate would require materiel developers to include the associated total cost of energy over the complete lifecycle of a tactical system during its development.

It has not been clear as to why DoD has not aggressively pursued technological alternatives to petroleum-based fuels and power propulsion. Perhaps it could be rooted in the lack of funding, competing priorities, or both. However, a means to begin the process of considering alternative technologies would be to implement an energy efficiency KPP and an enforceable FBCF policy.

The Need for More Energy-Efficient Combat Systems

Combat and combat related systems generally are inefficient in their use of fuel. This represents a major constraint on the operational effectiveness of US forces and translates directly into poor endurance and persistence in the battlespace. Due to the fuel-inefficient nature of combat platforms, they are forced to use more time transiting to fuel points/sources instead of residing on base or station, where more of them are needed to maintain a continuous presence. Improvements in the efficiency of platforms therefore would enable US forces to increase their in-theater effectiveness by spending more time on station relative to in transit, and by allocating fewer of their assets to sustain a given number at that station. Platform inefficiency affects operational effectiveness in other ways as well. Moving and protecting fuel through a battlespace requires significant resources. It constrains freedom of movement by combat forces, makes them more vulnerable to attack, and compels them to redirect assets from combat operations to protection of supply lines. Thus, the need to move and protect fuel detracts from combat effectiveness in two ways: adding to sustainment costs and diverting and endangering in-theater force capability. [25]

The payoff to DoD, in terms of mission effectiveness and human lives, is probably greater than for any other energy user in the world. More efficient platforms would enhance range, persistence, and endurance. They also would reduce the burden of owning, employing, operating, and protecting the people and equipment needed to move and protect fuel from the point of commercial purchase to the point of use. An important implication is that increased energy efficiency of deployed equipment and systems will have a large multiplier effect. Not only will there be direct savings in energy cost, but combat effectiveness will be increased and resources otherwise needed for resupply and protection redirected. Truck drivers and convoy protectors can become combat soldiers, increasing combat capability while reducing vulnerabilities caused by extensive convoys. In short, more efficient platforms increase warfighting capability. [26] Taking advantage of alternative technologies to make platforms more efficient would also increase the survivability of soldiers on the battlefield.

Considering the Fuel Demands of Forward Operating Bases

While the Army consumes less fuel than the Air Force, that fuel is generally difficult to move and protect. As shown in Table I[27], the Army's peacetime and wartime fuel consumption patterns differ considerably. During peacetime, fuel consumption by Army aircraft makes up almost 50% of its total. However during wartime, generators become the largest single fuel consumers on the battlefield. Generator sets in Iraq, used for space-cooling, seem especially amenable to innovative technical solutions for improved fuel and load efficiency. Solutions such as nonrefrigerative cooling systems, coupled with design improvements, would provide more efficiency and passive cooling for tents. In addition, solar powered refrigeration units have been successfully used by the United Nations and other international aid agencies in a number of developing countries. [28]

Table I. Peacetime/Wartime Fuel Consumption Rates

Category	Peacetime OPTE MPO	Wartime OPTE MPO
Combat vehicles	30	162
Combat aircraft	140	307
Tactical vehicles	44	173
Generators	26	357
Nontactical	51	51
Total	291	1040

The February 2008 Report of the DSB Task Force on DoD Energy Strategy scrutinizes the military and builds a strong case emphasizing the need for DoD to do something now about its dependence on and growing demand for fossil fuel.

Sources of Petroleum

Petroleum Supply and Demand for the US Military

Typically, operational forces do not ship fuel from the United States into a given theater but buy it from sources near theater; DoD operations are entirely dependent on the commercial global petroleum market for its supplies. From a geostrategic perspective, most of the countries exporting oil are far from free and democratic (e.g., Saudi Arabia and Iran), are hostile to the United States (Iran and Venezuela), or are corrupt and fragile (such as Nigeria). Table II[29] shows the top oil exporting nations. (Note: The chart shows oil exported in total to all world consumers and not just to the United States.) Citizens of some of these nations are suspected of using their oil revenue to sponsor terrorist activities against the United States. Reduced fuel consumption has long been a national aim, yet demand continues to grow. By addressing its own fuel demand, DoD can serve as a stimulus for new energy efficiency technologies and help limit national dependence on foreign oil. [30]

Table II. Petroleum Exporting Countries

Country	Net Oil Exports (mbpd)
1. *Saudi Arabia*	8.73
2. Russia	6.67
3. Norway	2.91
4. *Iran*	2.55
5. *Venezuela*	2.38
6. *United Arab Emirates*	2.33
7. *Kuwait*	2.20
8. *Nigeria*	2.19
9. Mexico	1.80
10. *Algeria*	1.68
11. *Iraq*	1.48
12. *Libya*	1.34
13. Kazakhstan	1.06
14. Qatar	1.02
Includes countries with net exports exceeding 1 million bpd in 2004. (OPEC members in italics.)	

Comparing the oil exports in 2004 from Table II to current imports shown in Table III,[31] it is evident that our dependence continues to increase. The countries we buy from may change, but most of our oil is still imported.

According to the Department of Energy website, these are the top 15 countries that the United States imports crude oil and petroleum from.[32] (It must be emphasized that these are only the top 15 countries; there are many more, too numerous to mention.)

December 2008 Import Highlights, as of February 27, 2009

The December 2008 Monthly data shows that two countries exported more than 1.30 million barrels per day to the United States. Including those countries, four countries exported over 1.00 million barrels per day of crude oil to the United States (see table below). The top five exporting countries accounted for 59 percent of United States crude oil imports in December while the top ten sources accounted for approximately 87 percent of all U.S. crude oil imports. The top sources of US crude oil imports for December were Canada (2.033 million barrels per day), Saudi Arabia (1.394 million barrels per day), Mexico (1.126 million barrels per day), Venezuela (1.028 million barrels per day), and Nigeria (0.869 million barrels per day). The rest of the top ten sources, in order, were Angola (0.553 million barrels per day), Iraq (0.519 million barrels per day), Ecuador (0.252 million barrels per day), Algeria (0.235 million barrels per day), and Brazil (0.208 million barrels per day). Total crude oil imports averaged 9.419 million barrels per day in December, which is a decrease of (0.504) million barrels per day from November 2008.

It is important to note that Table III only reflects oil imports and not petroleum imports. The Department of Energy has a corresponding chart that shows petroleum imports for the same period. Combining oil and petroleum imports, there was a total of more than 17.557 million barrels per day imported in December 2008.

Table III. Current Oil Imports to the United States

Crude Oil Imports (Top 15 Countries) (Million Barrels per Day) (Note: The data in the tables above exclude oil imports into the U.S. territories.)					
Country	**Dec-08**	**Nov-08**	**YTD 2008**	**Dec-07**	**YTD 2007**
CANADA	2.033	2.028	1.931	1.796	1.888
SAUDI ARABIA	1.394	1.487	1.506	1.675	1.447
MEXICO	1.126	1.296	1.185	1.234	1.409
VENEZUELA	1.028	1.080	1.041	1.246	1.148
NIGERIA	.869	.775	.923	1.210	1.084
ANGOLA	.553	.450	.504	.439	.498
IRAQ	.519	.476	.627	.378	.484
ECUADOR	.252	.222	.214	.195	.198
ALGERIA	.235	.381	.311	.348	.443
BRAZIL	.208	.280	.231	.171	.165
KUWAIT	.194	.292	.206	.158	.175
COLOMBIA	.148	.160	.178	.113	.137
CHAD	.105	.075	.102	.092	.077
CONGO (BRAZZAVILLE)	.095	.061	.067	.031	.063
AZERBAIJAN	.078	.071	.073	.134	.057

Fluctuating Cost of Fuel in a Tight Global Market and Its Effect on DoD's Energy Budget

In recent years, tight supplies and strong demand have characterized the oil market, putting upward pressure on prices. Americans, certainly including the military, endured a most painful example of this during the summer of 2008, when oil prices surged to historic levels. Fiscal Year 2007 is the first year the DESC changed its standard price in mid-year. This price is used by government customers to budget for fuel purchases. In real terms, world oil prices are currently near historic highs, approaching those of the oil crisis of the early 1980s. From 2004 to 2006, DESC fuel sales more than doubled from $5.9 B to $12.4 B[33], with most of the increase being due to rising prices for petroleum products. [34]

Such rapid increases in the commodity cost of fuel get leadership attention because of their effect on budgets. Department of Defense operates on a six-year Future Year Defense Plan funding horizon. Increases of this magnitude mean that large sums of money must be reprogrammed in order to meet operating costs, wreaking havoc on programs from which the funds are taken.[35]

Understanding the Dilemma of Earth's Remaining Oil

We have long since passed the point at which the Earth had boundless oil-rich areas, particularly in the United States, where there were seemingly endless easily extractable flows of fossil-based oil. Those days are long gone, and this notable fact demands that we seek out alternative energy technologies to meet our military needs.

Peak oil is the point in time at which roughly half of the extractable oil on the planet has been used and future production enters terminal decline. Such a decline would put strong, persistent upward pressure on prices, which it has.

In July 2007, the National Petroleum Council (NPC), an industry advisory group, conducted a study for the Secretary of Energy titled "Facing the Hard Truths about Energy: A comprehensive view to 2030 of global oil and natural gas." It concluded that while the world is not running out of energy resources, there are significant challenges to meeting projected total energy demand. Until this report, the NPC had been generally optimistic about future petroleum supplies. It found that the United States must moderate its growing demand for energy by increasing the efficiency of its transportation, residential, commercial, and industrial sectors; expanding and diversifying production from other energy sources; enhancing long-term research into energy supply and demand; and developing the legal and regulatory framework to enable carbon capture and sequestration. (See Appendix A for explanation of Peak Oil Theory.)

In February 2007, the Government Accountability Office (GAO) published a study entitled "Uncertainty about Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production." It identified 22 separate studies on peak oil conducted since 1996 and noted that most predict peak oil to occur between now and 2040. It noted there is no coordinated federal strategy to reduce uncertainty about the peak's timing or to mitigate its consequences.[36]

Among the implications for DoD are that after peaking, prices for fuel will be even higher.[37] Make no mistake about it, it is time for the US military to rethink its energy strategy given the geopolitical, economic and national security implications associated with the future availability of oil.

Analysis and Findings

A plethora of alternative energy technologies exist that could potentially benefit the operational Army in achieving independence from foreign petroleum. However, it has been observed that only a few technologies warrant pursuit in the near term. Hybrids, fuel cells, and alternative fuels are where plausible near-term gains could be achieved. There are many variants of hybrid and fuel cell nonmechanical propulsion, and alternative fuel technologies being researched, but the focus is narrowed when it comes to how applicable they are to ground and air tactical systems. There are new mechanical propulsion technologies identified that have much potential to enhance fuel efficiency in tactical ground and aircraft systems. There is also a technology mentioned that is worth pursuing in the long term that could yield major benefits in the future. It is important to note that it was found that most of the technologies many of the various organizations are working on were based in conventional internal combustion engine technology, which included much of the hybrid research. There is not much innovative exploration being done in new propulsion technologies that ventures away from fossil-fuel-using technologies.

Alternative Fuels/Energy

When considering alternative fuels, it is very important to understand that the primary consideration must be energy density. Fuels may either be derived directly from natural resources (e.g., petroleum, natural gas or uranium) or by a method of storing energy in a more convenient form (e.g., alcohol from biomass or hydrogen from electrolysis of water). As such, the stored energy density is a useful metric for comparing various fuels. Since fuels may be solid, liquid or gaseous, both gravimetric (energy per unit mass) and volumetric (energy per unit volume) energy densities are important. Figure 2[38] compares the volumetric and gravimetric energy densities of liquid hydrocarbon, alcohol, and hydrogen fuels along with those of batteries. Other than uranium, the liquid hydrocarbons offer the most attractive combination of volumetric and gravimetric energy densities. The alcohols offer approximately half of the energy density of the liquid hydrocarbons. Although all fuels require containment, the only fuels on the chart that sustain a significant impact on energy density due to containment are the hydrogen fuels (due to the gaseous nature of hydrogen). Liquid hydrogen requires cryogenic storage at -253° C, which consumes energy equal to about 30% of the energy being stored. Pressure vessels required to contain gaseous hydrogen impose a penalty of 10 to 20 times the weight of the hydrogen being stored. The impact is to move the effective gravimetric energy density of hydrogen fuels substantially to the left on the chart. Another containment technology for hydrogen is to combine hydrogen with metals to form metal hydrides. However, the weight of the metals required and the low fraction of hydrogen stored combine to produce low resulting energy densities. Additionally, heat is typically required to release the hydrogen from the hydride when it is required. For reference, the best batteries offer energy densities 30 to 50 times lower than liquid hydrocarbon fuels.[39]

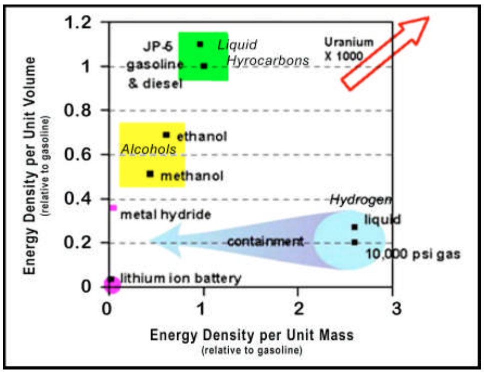

Figure 2. Energy density of fuels.

For reference purposes, Table 4[40] lists volumetric and gravimetric energies for various fuels relative to the energy density of gasoline. The lithium-ion battery, representing the most energy-dense fielded battery technology, is included for comparison purposes. [41]

Table IV. Volumetric and Gravimetric Energies

Fuel	Energy per Unit Mass	Energy per Unit Volume
Gasoline	1.0	1.0
JP-5	0.97	1.1
Methanol	0.44	0.51
Ethanol	0.61	0.69
Liquid Hydrogen	2.6	0.27
Metal Hydride	0.046	0.36
Methane (@ 3,000 psi)	1.1	0.29
Hydrogen gas (@ 3,000 psi)	2.6	0.06
Liquid propane (@ 125 psi)	1.0	0.86
Methane (@ 10,000 psi)	1.1	0.97
Hydrogen gas (@ 10,000 psi)	2.6	0.2
Lithium ion battery	0.019	0.035

Hydrogen Fuels and Hydrogen-Powered Internal Combustion Engine

Despite the limiting physics of hydrogen when considering its energy density volumetric characteristics, much research continues to be done because of its natural abundance and environmentally friendly nature. Hydrogen must be contained under high pressures to allow for form-and-fit and suitable integration into an automobile type configuration. This high compression also introduces a certain degree of hazard to personnel safety. These challenges do not make hydrogen entirely suitable for tactical vehicle systems yet. Consequently, most future research remains to be in liquid hydrocarbon fuels (JP-8, diesel, and gasoline) for tactical systems. Because more work needs to be done to overcome hydrogen's energy density reduction and safety challenges, current research has focused on its use in nontactical hybrid configurations integrated with conventional internal-combustion-engine petroleum-based technologies. Hydrogen fuel has much potential to drastically reduce dependence on petroleum-based fuels and therefore research must be aggressively continued.

Considering that the first hydrogen-power-based engine was conceived in 1820[42], much of the gains in this technology have been within the last 30 years, with most technological progress being more aggressively pursued in the last 10 or so years. The Ford and, particularly, BMW automobile manufacturers have been leading progress with the advent of the hydrogen-powered internal combustion engine (ICE). Ford's truck version only uses hydrogen fuel, while BMW's engine is capable of using both hydrogen and gasoline.[43] Ford's partner Mazda has recently produced a dual hydrogen/gasoline version, but it is a rotary-engine-based design.[44] The BMW design has more possibility for military application in the near term, since it is based on the conventional ICE design currently used in military systems, which could potentially be converted with some small degree of redesign. The alternative would be to introduce a new power plant design, integrating the less fuel-efficient Mazda rotary engine, which would require major remanufacturing, alter logistical support, and would take more time at higher cost.

The attraction of the hydrogen-powered ICE is its potential for rapid deployment of hydrogen-fuel-based vehicle technologies. This would help make a hydrogen refueling and production infrastructure economically more viable and cost effective, which is currently lacking in industry. Hydrogen ICEs can be manufactured more cheaply than fuel cells, only about 15% more expensive than conventional gasoline engines, or probably less if serious mass production takes hold. There are already production facilities in place to make them by the millions. These could be the first vehicles that take America into the hydrogen economy.[45] There are other benefits to hydrogen-powered ICEs. They can run on pure hydrogen or a blend of hydrogen and compressed natural gas (CNG). (Like hydrogen, natural gas is quite abundant in the United States.) This fuel flexibility is a very attractive means of addressing the widespread lack of hydrogen fueling infrastructure in the near term. Hydrogen-powered ICEs also have many operating advantages. They perform well under all weather conditions, require no warm-up, have no cold-start issues (even at subzero temperatures), and are highly fuel efficient—up to 25% better than conventional spark ignition engines.[46] Research is expected to continue to yield marked improvements.[47]

Driving range is perhaps the biggest hurdle for hydrogen-powered ICEs using currently available fuel tank designs, because it is very difficult to store enough compressed hydrogen onboard a car or light truck to give it a driving range equivalent to that of a standard tank of gasoline. The situation with liquid hydrogen is better compared to gaseous hydrogen, but even these tanks take up considerably more room than gasoline tanks, plus liquid hydrogen has issues with boil-off of fuel during extended periods of inactivity. Researchers are working on materials that could lead to higher-density hydrogen storage capability, but those solutions are still years away.[48]

Government researchers are also exploring this technology. The US Army Tank Automotive Research, Development and Engineering Center (TARDEC) National Automotive Center (NAC)[49], in collaboration with the Department of Energy (DoE) and Chevron Oil Company, are conducting an assessment of a converted ICE hydrogen fueled vehicle. This prototype is being evaluated over an extended period of time at the Selfridge Army National Guard base in Michigan in an effort to truly determine its viability for tactical vehicle application.[50]

The question of hydrogen fuel availability comes into play when considering deployed forces. Until hydrogen fuel stations have proliferated worldwide, research must be done on ways to produce this type of fuel. There are a number of industry leaders—such as Chevron Oil Company, partnered with DoE and TARDEC, and Air Products and Chemicals, Incorporated, a major developer in plant manufacturing and fueling stations—that can certainly help bridge this logistical gap.[51] With the help of industry leaders, perhaps designs to enable production of hydrogen aboard ships to support combat operations in austere remote locations, and other hydrogen production and logistical supply methods can be devised.

Biojet/BioFuels

To offset the cost of imported petroleum for the military, Defense Advanced Research Projects Agency (DARPA) is conducting research, with academia, to replace jet petroleum type 8 (JP-8) with biological based fuels that are made from indigenous resources. As mentioned earlier, JP-8 is used by the military in everything from tanks and aircraft to generators that power base camp operations.

DARPA's initial biofuels research focused on converting agricultural crop oils (canola, jatropha, soy, palm oils, and others) to a JP-8 surrogate or biojet/biofuel. Currently the most promising research has expanded to cellulosic and algal feedstocks to produce a second generation biojet that is noncompetitive with food sources.[52] According to TARDEC NAC experts, agricultural crop oil-based biofuels, or the first generation, showed dissimilar composition and could not be approved for use in tactical vehicles. Moreover, second-generation biojet fuel has great promise, and continued efforts in this research will pay dividends for the military operational force.[53]

Fuel Cells

The potential of fuel cell propulsion technology has advanced to a point where a number of US federal agencies are heavily researching. As part of the same effort mentioned above for hydrogen-powered ICE, the US Army TARDEC NAC, DoE, and Chevron are working together on such technology and are evaluating a fuel cell hydrogen fueled commercial vehicle to demonstrate its fertility and feasibility for military application.

Automobile manufacturers like Honda are leading the way in fuel cell innovation and advancement. Honda will be making available at its dealerships in 2009 the world's first production fuel-cell-powered automobile.[54] In 2002, Honda had the first automobile to be certified by the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB), making it the first fuel-cell automobile in history to be approved for commercial use.[55] Constant evolution in technological improvements over the last seven years has made it ready for use by the consumer. Capitalizing on such advancements could very well yield the type of fuel cell applications beneficial to the military.

Advances are rapidly happening in this area. A key process in fuel cell technology is the separation of the hydrogen atom from a gas mixture. Most recently two chemists at Northwestern University have developed a way to make this separation easier and more effective with new porous materials.[56] This is just an example of how fast this technology is advancing.

Hybrids

Electrics

Elements of the DoD, specifically TARDEC, DARPA and US Marine Corps, have shown great interest in hybrid electric technology for some time. They have been actively engaged in a research, development, and engineering program aimed at developing and fielding combat and tactical hybrid electric vehicles. In the past, these DoD partners converted the mechanical drive systems to an electric drive configuration for conventional M2 (Bradley fighting vehicle), M113 (armored personnel carrier), and HMMWV to investigate the viability of the hybrid electric drive technology. It was substantially demonstrated that this technology had potential benefits and was feasible. Encouraged by the potential payoffs of hybrid electric drive for military applications, TARDEC continues its research and development efforts. The TARDEC NAC hopes to develop hybrid electric solutions to support ongoing and future vehicle programs such as the Future Tactical Truck System (FTTS), Joint Light Tactical Vehicle (JLTV) system, and Future Combat Systems (FCS) manned and unmanned ground vehicles.[57] However, lack of funding constrains the ability to conduct the appropriate and necessary level of research and the appropriate quantity of actual military platforms/system assets to adequately complete the engineering prototyping necessary to advance this viable technology for military application.

Hydraulic

A little-known fact is that the EPA's National Vehicle and Fuel Emissions Laboratory (NVFEL) in Ann Arbor, Michigan has been for many years the research leader in a number of automotive technological advancements. It is engaged in engine, alternative fuels, and hydraulics research. Hydraulics research has shown much potential for military application. Since 2005, NVFEL has been partnered with TARDEC NEC, United Parcel Service (UPS), and Eaton-International Truck and Engine Corporation, making monumental strides in hydraulic hybrid technology. This technology uses a hydraulic energy storage and propulsion system in the vehicle. The hydraulic system captures and stores a large fraction of the energy normally wasted in vehicle braking and uses this energy to help propel the vehicle during its next acceleration. The hydraulic system also enables the engine to operate more efficiently when it is needed.[58]

Hydraulic hybrids draw from two sources of power to operate the vehicle—the diesel or gasoline engine and the hydraulic components. In other words, a typical diesel-powered or gasoline powered vehicle can be fitted with hydraulic components as a secondary energy storage system. The primary hydraulic components are two hydraulic accumulator vessels (a high-pressure accumulator capable of storing hydraulic fluid compressing inert nitrogen gas and a low-pressure accumulator) and one or more hydraulic pump/motor units. [59]

One major benefit of a hydraulic hybrid vehicle is the ability to capture and use a large percentage of the energy normally lost in vehicle braking. Hydraulic hybrids can quickly and efficiently store and release great amounts of energy due to a higher power density. This is a critical factor in maximizing braking energy recovered and increasing the fuel economy benefit.

While the primary benefit of hydraulics is higher fuel economy, hydraulics also increase vehicle acceleration performance. Hydraulic hybrid technology cost-effectively allows the engine speed or torque to be independent of vehicle speed, resulting in cleaner and more efficient engine operation. [60] The current hydraulic hybrid technology has a parallel design that is integrated to compliment the vehicle's existing conventional drive train (transmission and driveshaft system), as shown in Figure 3[61]. This parallel hybrid produces a fuel economy improvement in the 20 to 40 percent range, which is significantly better than hybrid electric systems.[62]

Hydraulic hybrid systems create a unique opportunity to optimize engine operations. EPA has produced research concept vehicles that demonstrate the hydraulic technology. One concept vehicle is an urban delivery truck that uses hydraulic "launch assist." This delivery truck retains its conventional engine and transmission but adds a hydraulics package optimized for fuel economy. The next generation of hydraulic vehicles involves fully integrating hydraulic technology, which will be the series design configuration shown in Figure 3[63]. In this configuration, the full hydraulic hybrid replaces the conventional drive train with a hydraulic drive train and eliminates the need for a transmission and transfer case.[64] The EPA's modeling of full-series hybrids predicts they will offer a fuel economy boost of 40 to 80 percent.[65]

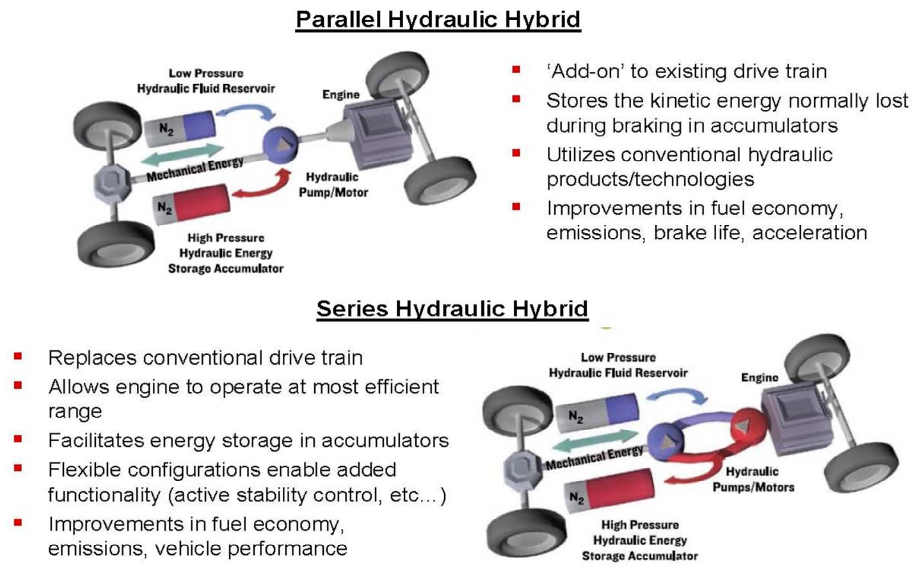

Figure 3. Parallel and series hydraulic hybrid design.

The Army's TARDEC NAC has been very interested in this technology for its claim to enable the recovery and reuse of energy normally lost in conventional vehicles during the act of braking, major reduction in maintenance costs, and that it may reduce "engine-on" operation to improve fuel economy. It has also partnered with the Bosch Rexroth, which is currently installing the Series Hydraulic Hybrid technology on an International Truck and Engine Corporation Military Extreme Truck-Military Version (MXT-MV) medium-duty truck. (The MXT-MV is shown Figure 4.[66]) The MXT-MV will be operational and begin demonstration of this military prototype in fiscal year 2009.[67]

Figure 4. MXT-MV medium-duty truck.

Though the hydraulic hybrid technology has much potential for military application, it is also hampered by a lack of funding to do the aggressive research necessary to bring this type of technology to the Warfighter sooner rather than later, or worse—not at all. This technology offers high payoff at an anticipated low cost, and it perhaps can be acquired in a relatively short period of time for integration into the next generation of military vehicles.

Energy Storage

An area that needs much advanced research attention is battery electrical energy storage. Fortunately, there are some elements of the federal government already focusing on this area.

Although there has been much advancement in energy storage technology, it still remains the single greatest obstacle to achieving the enabling technologies necessary to advance fuel cell, hybrid electric, and pure electric mobility systems. Technological barriers to achieving high specific power, high specific energy/density, high charge acceptance in recharging, long cycle life, low temperature tolerance, and minimal exothermic tendencies must be overcome. Hence, further development is required.[68]

Asian countries are, by far, the world leaders in technological advancement in the recent past and for the foreseeable future. Unfortunately, the United States has lagged behind for many years and is now beginning to make small steps trying to catch up. It will take many years for America to close the gap if we continue on the fossil fuel path and do not commit the necessary resources to accelerate advances in energy storage technologies. Asian companies currently have about 80% of the global market share for this technology, and they continue to hedge their bets by investing in several green and fuel-efficient technologies—more specifically, battery energy storage.[69] The ideal energy storage technology currently does not exist. It can be said that Asia is working relentlessly toward that end, and America must do the same.

The Department of Energy, when asked what primary research area has recently become a top priority, answers battery energy storage. This new top priority was briefed by the acting director of Department of Energy to President-Elect Obama's transition team.[70] The renewed emphasis in this area is predicated on our nation's need for energy independence from foreign imported petroleum/oil, and to support our nation's movement toward being better environmental stewards for green technologies.[71]

The ever growing electric power needs of modern combat systems have been driving the need for electrical storage capacity for some time. As previously noted, the Army's TARDEC NAC has engaged in designing high-power, high-energy-density lithium-ion batteries for use in hybrid electric vehicle propulsion systems. This energy storage research area is being considered for other critical applications including auxiliary power units, plug-in hybrids, silent watch energy storage, pulsed power delivery applications for direct-energy weapons, and future hybridized power source designs for fuel-efficient vehicles.[72] This is all being done principally to support emerging new operational requirements for tactical platforms to operate temporarily in a stealth mode, to power electrical systems on-board future mobile combat systems, and to lessen the Army's dependence on petroleum based fuels.[73] With a fitting amount of monetary resources infused into the TARDEC's program, high-powered and high-energy storage technologies will be advanced enough to meet the real and tangible needs of the upcoming future mobile tactical systems.

Technologies to Improve Platform Energy Efficiency

The following section highlights technologies that can be applied to improve energy efficiency in existing fossil-fuel-powered propulsion-based systems.

There are huge gaps between the efficiency of current platforms and what is technically and economically achievable in the future. Fortunately, technology exists to enhance the fuel efficiency of air, maritime, and ground platforms. There is enormous technical potential to cost-effectively become more fuel efficient and by so doing to significantly enhance operational effectiveness.[74]

There are three technologies with the potential to fundamentally alter DoD capabilities and enable new concepts of operations. These offer the potential of double-digit percentage improvements in energy efficiency over current technologies, and to propel our domestic industrial base to new levels of performance. They have the potential not only to improve DoD's capabilities, but to benefit the nation through commercial adoption.[75] The three technologies are

- blended wing body for fixed-wing, heavy-lift aircraft;
- variable speed tilt rotor for vertical lift aircraft; and
- Badenoch blast-bucket design concept for light-armor ground vehicles.

The three are shown in Figure 5,[76] with rough estimates of their operational gains and fuel savings. Just as for ground platforms mentioned earlier, it is also suggested that alternate fuels for specific missions and systems (e.g., hydrogen fuels for long-range and/or high-speed aircraft) could offer the potential for much higher energy densities than current fuels. Such fuels could impart important operational capability benefits. As noted earlier, the potential for such fuels suggests that basic research in this area should be pursued.[77]

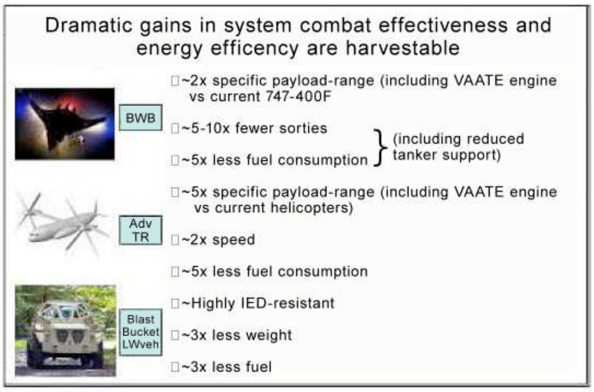

Figure 5. Examples of fundamental energy efficiency disruptive breakthrough technologies.

Blended Wing Body

The blended wing body (BWB) design would fundamentally alter the design of heavy aircraft such as tankers, bombers, and transports (DoD's single largest fuel use). It offers the possibility of two times the gain in range and payload and of five to ten times the gain in system-level fuel efficiency (see Figure 6[78]). If the technology can be successfully applied to both tankers and bombers, the potential exists for far fewer sorties needed to accomplish a given mission. The enhanced range of both bombers and tankers would offer the possibility of far fewer aircraft devoted to a single mission, freeing aircraft to conduct other missions or to focus more firepower on a given target.[79]

The overall efficiency and productivity improvements enabled by BWB designs are striking. For example, the enhanced fuel efficiency of a BWB relative to a B52 bomber and a KC-10 tanker could mean that a mission to deliver 100K lbs of munitions that today requires one and a half B52 bombers and nine KC-10 tankers might be replaced by one and a half B52s and three BWB tankers or by one BWB bomber and only one BWB tanker. The combination of efficiency improvements to both the combat and support aircraft creates the possibility of order-of-magnitude savings to achieve this particular mission, freeing up resources for other purposes. It is a prime example of how enhancement of fuel efficiency can translate into enormous potential for increased operational effectiveness. [80]

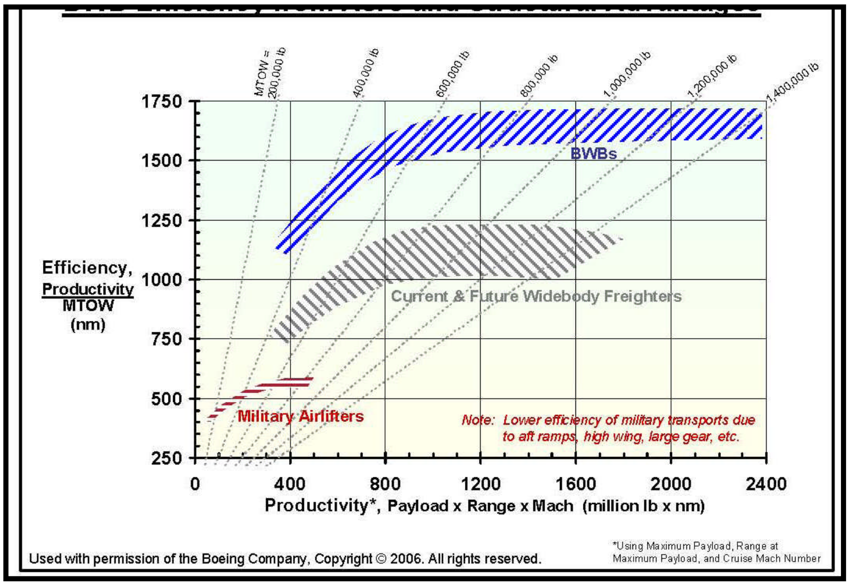

Figure 6. BWB efficiency from aero and structural advantages.

Variable Speed Tilt Rotor

Current rotorcraft and those in development continue to embody decades-old technology that allows only small incremental gains in fuel efficiency and performance. However, emerging vertical lift technologies and new rotorcraft designs, specifically advanced tilt rotor designs exploiting variable speed rotors, hold promise of far greater range, speed and operational flexibility (e.g., sea base operations), with substantially reduced fuel consumption. Figure 7[81] compares the cruise efficiency and speed of various vertical lift aircraft. National Aeronautics and Space Administration (NASA) and DoD analyses show advanced tilt rotors with 100–150% greater aerodynamic cruise efficiency than the V-22 and 300–400% better efficiency than current or new design helicopters based on improved lift/equivalent drag. Additionally, new technologies available in engines, structures, drives, flight controls, and subsystems make significant improvements possible in empty weight, propulsive efficiency, and overall fuel economy. In effect, such aircraft may be able to achieve efficiency capabilities approaching that of the C-130 cargo plane, and do so with a short takeoff and landing capability. They hold promise of rapid, long-range vertical insertion of ground forces for mounted maneuver—a capability currently unobtainable.[82]

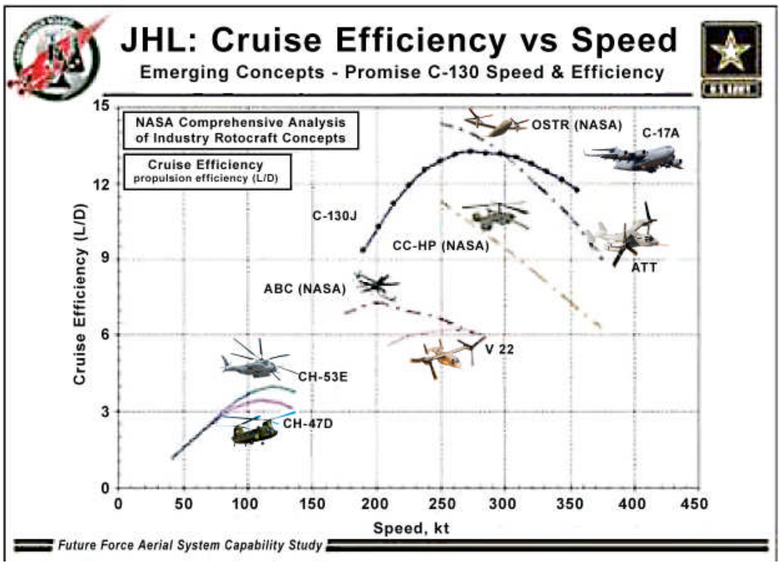

Figure 7. Cruise efficiency, speed of vertical lift of aircraft compared.

Army analysis indicates that the operational benefits of advanced tilt rotor designs with variable or advanced configuration rotors are compelling. As an example, a notional Future Combat System (FCS) Brigade Combat Team (BCT) requires approximately 2,215 short tons of cargo, including fuel, every three days. Using current platforms, a typical delivery scenario covers a distance of 600 km and requires using an intermediate staging base and a combination of C-130s and CH-47Fs. A tilt rotor aircraft employing a variable speed rotor would eliminate the need to transit the forward operating base and the need to use two types of aircraft. It would accomplish the mission in one third the flight time with 70% fewer sorties and less than half the fuel. Operationally, forces in the field could move more quickly, with less exposure time to hostile fire and with fewer aircraft resources, so that a given fleet could perform a broader set of lift or maneuver operations than current aircraft and do so with far greater fuel efficiency. This also creates the possibility of eliminating the forward operating base altogether, including the ground time, personnel, resources and attack vulnerability associated with offloading the fixed wing assets and reloading the vertical take-off and landing (VTOL) aircraft.[83]

In a joint multi role (JMR) configuration, an advanced, variable-speed tilt rotor or other advanced rotorcraft design has the potential to greatly improve the range, mission loiter time and speed of the Army and Marine rotary wing attack/escort and armed reconnaissance/VTOL intelligence, surveillance, and reconnaissance (ISR) fleet while providing up to a 50% reduction in fuel demand when operating over extended (expeditionary) distances. These advancements in mission performance would be essential to support escort for advanced lift fleets and landing zone security and protection operations for mounted vertical maneuver operations. These designs would also be much more suited for operations for naval vessels and future advanced sea bases.[84]

Badenoch "Blast Bucket" Light Armored Ground Vehicle

In Iraq, Army ground vehicles have proven highly vulnerable to improvised explosive devices (IEDs). To mitigate this problem, the Army has up-armored its vehicles. However, this has reduced fuel mileage from about 10 mpg for a standard HMMWV to about 4 mpg. This significantly reduces their range and increases the amount of fuel they require. Further, the additional weight puts the vehicle beyond the design limit for its suspension, brakes, and tires. This results in frequent tire blowouts, vehicle rollovers, and other accidents with serious or fatal consequences for soldiers[85].

There are currently two programs intended to replace the HMMWV: the Joint Lightweight Tactical Vehicle (JLTV) and the Mine-Resistant, Ambush Protected (MRAP) Vehicle. Both are significantly heavier than the current up-armored HMMWV, sending battlefield fuel demand in the opposite direction it needs to go. But there may be another way. Research on lightweight structural materials and innovative design concepts has demonstrated the potential to produce survivable, militarily capable ground combat systems that weigh less and use less fuel than current systems. One example, known as the Badenoch vehicle, was developed at the Georgia Tech Research Institute (GTRI) with funding from the Office of Naval Research.[86]

The Badenoch vehicle weighs less than half as much as an up-armored HMMWV, has much greater fuel efficiency, carries as many soldiers, provides better ability to fight from the vehicle, and vastly improves protection against blast and projectiles. It has a new lightweight armor that has undergo developmental testing by GTRI, and is made from two layers of aluminum sandwiching and a combination of unique materials, which accounts for its lightweight, fuel-efficient construction. This new design produces reasonably thin armor and is able to resist much larger, higher velocity projectiles than existing, much heavier, steel armor.[87] It also packages National Association for Stock Car Auto Racing (NASCAR) tested safety and reliability features into an agile, multipurpose vehicle to replace the familiar HMMWV, which was not intended to be used in combat situations involving shoulder-fired rocket-propelled grenades and IEDs. The concept and a number of technical innovations are shown in Figure 8.[88] The blast bucket vehicle could be fitted with hybrid electric and opposed-piston, opposed-cylinder engine technology to achieve a 50% increase in fuel efficiency in wartime conditions and a 200% increase in garrison or local use.[89] (See Appendices B and C for explanations of blast bucket vehicle design and opposed-cylinder engine technology, respectively.)

Figure 8. Badenoch "blast bucket" vehicle.

The vehicle uses onboard computers to integrate steering, suspension, and brakes. It also has an integrated chassis. These unique design features significantly enhance safety and performance in mobility at increased fuel efficiency, which is lacking in the HMMWV and recently fielded MRAP. There was also nothing found that indicated that JTLV would have similar capabilities.[90]

The vehicle will have advanced power-generating capabilities—portable power. The ONR wants the vehicle system to provide up to a megawatt (one million watts) on the spot to power emerging battlefield concepts such as electrostatic armor, which uses electricity for extra protection, and bunker-busting rail guns. Such power could run command posts and communications gear and even power small villages, which could eliminated the need for inefficient petroleum-using generators.[91]

As mentioned above, Badenoch vehicle plans call for a hybrid engine that combines diesel and electric power plants. This setup would not only aid power generation, but offer a silent electric mode when stealth is needed. Moreover, the new engine will give the vehicle system the critical ability to move more swiftly out of harm’s way. This hybrid engine design will have much more horsepower than the HMMWV engine with far greater fuel efficiency. Plans call for the unloaded vehicle to go from zero to 60 miles an hour in 4.8 seconds.[92]

The fuel savings alone would result in reduced logistics needs and significant gains in range. Moreover, the blast bucket concept would better protect soldiers utilizing light vehicles and provide them more combat options. If the concept works as designed, it would greatly reduce the ability of enemy combatants to hinder light mobility assets and to inflict casualties on US forces. [93]

This problem of an efficient, survivable, lethal ground combat system is of such high importance to DoD’s ability to fight that the next-generation vehicle should be the subject of intense development, design, and competitive prototyping. There are many examples in the areas of commercial vehicles, racing, and aerospace where survivability has not required more mass. Armor constitutes half the total gross vehicle weight of some variants.[94]

Technology to Aggressively Research Now for the Future

There has been significant great technological progress made over the last 40 years in the areas that are about to be discussed. A renewed commitment to these areas is believed would produce the kind of advancements that could be used for military application in mobile combat systems. With that said, these next technologies are far reaching but are believed to have merit for their potential to dramatically reduce or eliminate the logistical burden for supply of fuels to austere tactical operational environments.

At the end of World War II, the US Army began using nuclear power for peacetime power generation. With heightened awareness of the cost of energy resources from the war, a major focus was to how to become less dependent on petroleum-based energy sources, which were very costly and carried an extreme logistical burden even during the 1940s. Seeing much more positive benefits for mankind, the Army began to explore this new source of energy in an effort to become more energy independent. This initiative was the "Army's Nuclear Power Program."

In 1950s, the Army had fully operational nuclear power plants—the first in our nation. These plants provide electrical energy to offset the need to procure from local power companies. Because of the successes in the nuclear program, the Army explored the possibility of small mobile reactors to provide electrical power to support operational deployed units, portable plants that could be erected and disassembled and relocated, and nuclear powered train for the Transportation Corps for transport in remote area. They also explored the possibility of producing synthetic fuel and using nuclear energy to power batteries of electric-powered vehicles. By the early 1960s, there were a few portable plants built and even a nuclear power plant on a couple of ships. In the early 1970s, despite the nation's existing oil crisis and study group results indicating that nuclear power was a viable alternative to continued dependence on commercial fossil fuel energy, DoD leadership took no steps to implement any nuclear initiative. Instead, DoD migrated back to the use of conventional energy by way of nontactical generators.[95] Perhaps the technology was not mature enough, requiring higher levels of shielding from heat and radiation or better processes for proper disposal of wastewater, or perhaps the politics of the time discouraged its use; most likely, all of the above contributed. Whatever the reason, the Army and our nation missed a real opportunity for progress in nuclear technology.

During the heyday of this atomic era, many ideas were being explored like the ones mentioned above, including ideas that are considered extremely out-of-box thinking even today, such as nuclear powered automobiles. In fact, the Ford Motor Company seriously explored this application with the development of a concept automobile called the Nucleon in 1958. This vehicle was to be powered by a small nuclear reactor in the rear of the automobile. The vehicle featured a power capsule suspended between twin booms at the rear. The capsule, which would contain a radioactive core for motive power, was designed to be easily interchangeable, according to the performance needs and the distances to be traveled. The drive train would be integral to the power module, and electronic torque converters would take the place of the drive train used at the time. It was estimated that automobile would be able to travel 8000 km (5,000 miles) or more, depending on the size of the core, without recharging. At the end of the core's life, it would be taken to a charging station, which researchers envisioned would replace gas stations. The car was never built and never went into production. Not surprisingly, the main design hurdles were overcoming the dangers of radiation, nuclear waste, and the possibility of a small nuclear meltdown—particularly in the event of a traffic accident.[96] Had they been given the proper support, these technical matters might have been overcome by now.

Consider the possibility of where we could be today with nuclear technology if the military had continued on its aggressive path of researching this type of energy for military application. Who knows; perhaps today, the military would be employing portable and small form-fit transportable nuclear power systems on the battlefield for multiple uses and producing synthetic fuels aboard reactor-designed ships to support ground forces in remote locations, applications of nuclear technology that provide electrical propulsion energy to mobile combat systems, and, yes, using combat systems powered by nuclear energy. With the state of advancements made primarily by other countries today, maybe now is the right time for the military to pick up where the atomic era left off.

Recommendations

It is recommended that senior DoD leadership zealously pursue the alternative energy and propulsion technologies that are identified below for the US military, particularly the Army. These technologies are viewed as having the greatest potential for military application, achieve much cost saving over the life cycle of tactical ground and aircraft systems, and notably reduce or eliminate dependence on foreign petroleum sources. The recommended technologies are identified as those that are worth pursuing now and one that needs aggressive research initiated now given its potential benefits for the future.

Technologies Worth Pursuing Now:

- Alternative fuels/energy, specifically, hydrogen fuels used in hydrogen-powered internal combustion engines (ICE) and biojet/biofuels. Because there has been much advancement in these technologies in recent years, their proven use in some applications, and/or their advanced state of research, it would not take much more research to adopt them for military use.
  - Hydrogen-Powered ICE Vehicles. In 2007, BMW produced 100 of its dual hydrogen/gasoline fuel vehicles and put them in circulation in the United States, Europe, and Asia for operational field testing among select customers.[97] Since this technology has not been tested in a military operational environment, but has been operationally tested in a consumer market, it is rated at technology readiness level (TRL) 7. (See Appendix D for description and definition of technology readiness levels.)
  - Biojet/biofuels. In fall 2008, DARPA funded nearly $35 million to develop the second-generation biofuel derived from algae for use in Air Force jets and Army vehicles. Continued strong support for this research is necessary, and additional funding may be needed to achieve final milestones. Based on positive early assessments by TARDEC NAC, it is rated TRL 6.
- Fuel Cells. Because of advancements and recent innovation in the separation of the hydrogen atom from a gas mixture, which is a key process in fuel cell technology, along with its demonstrated capabilities, research should be continued with major funding. With President Obama's February 2009 signing of the American Recovery and Reinvestment Act of 2009 (ARRA), DoD is provided $300 million for research, development, test, and evaluation (RDT&E) programs managed by the Army, Navy, Air Force, and DoD-wide.[98] Although fuel cell research is specifically mentioned as eligible for funding under this program, it is unclear as to how much will be allocated for ground tactical systems. An appropriate amount of this ARRA funding should be allocated to

advance this technology to a primary power propulsion capability. It is also important to note that the Department of Energy (DoE) is receiving $2.5 billion under ARRA for its RDT&E programs, which include fuel cell research;[99] a formal partnering between DoD and DoE is recommended to rapidly advance this technology. Based on current advancements in the commercial sector, it is rated TRL 6/7.

- Electric and Hydraulic Hybrid Power Propulsion. These technologies have proven their worth in commercial vehicle applications and are strongly embraced by TARDEC NAC materiel developers, but need additional funding to advance the technologies for military application.
  - Electric Hybrids. Although TARDEC NAC has $12.6 million in its FY 2009 budget, it is only to continue evaluation of a few prototypes in a space-constrained environment and assess performance aided by modeling and simulation.[100] However, to accelerate the advancement of the technology to a point where significant enhancement in fuel efficiency can be achieved for FTTS, JLTV, and FCS over the 2–10% increases demonstrated in previous testing, then additional funding is needed. It is estimated that if funding levels are raised by an additional $10 million per year for the next 3–5 years, the appropriate hybrid electric technology could be achieved. This technology is rated TRL 7.
  - Hydraulic Hybrids. According to the TARDEC NAC FY 2009 budget, there does not seem to be any planned research and development effort for this technology, except initiation of small-scale demonstrations with the integrated MXT-MV tactical vehicle. Of the $14.2 million in the FY 2009 RDT&E budget, there only seems to be about $2.8 million[101] allocated for this technology, with nothing programmed for the future.[102] This is hardly enough to bring about the innovation necessary to advance this technology to a point where it can benefit the military in the near term. Funding should be doubled to $6 million per year for the next 2–5 years. Given EPA and TARDEC NAC past progress in advancing this technology, it is rated TRL 7.
- Electrical Energy Storage. This technology remains the single greatest obstacle to achieving the enabling technologies necessary to advance fuel cell, hybrid electric, and pure electric mobility systems, which are very much needed for JLTV and FCS systems

currently in development. Asian countries, which have been the leaders in battery technology for many years, continue to invest heavily in electrical energy storage research because of the demands in innovation by the worldwide automobile industry and the potential near-term technological breakthroughs that are to come. Since electrical energy storage is a prime research area for DoE, DoD should partner with DoE to advance this technology to yield the appropriate capability for combat systems required to operate in remote austere environments, and to offset potential dependence on Asian countries for this rapidly advancing technology. The TARDEC NAC Energy Storage Technology manager estimates that $3–$6 million per year for 5–6 years is needed to rapidly advance this technology for military purposes. This technology is rated TRL 6.

- Technologies to improve platform energy efficiency in existing fossil-fuel-power propulsion-based systems exist that offer the potential of harvesting dramatic gains in system combat effectiveness and energy efficiency, and they are:
    - Blended wing body for fixed-wing, heavy-lift aircraft. This type of aircraft technology would double the payload and range over traditional fixed-wing aircraft such as the 747-400F, require 5–10 times fewer sorties, and five times less fuel consumption, thereby reducing tanker support requirements. This technology is rated TRL 6.
    - Variable speed tilt rotor for vertical lift aircraft. This aircraft technology would increase payload and range five times over current military helicopters, achieve twice the speed, and consume five times less fuel. This technology is rated TRL 2/3, but given the state of existing similar and emerging technology, it could achieve TRL 6 or higher in three years, if aggressively pursued.
    - Badenoch blast-bucket design concept for light-armor ground vehicles. This armored vehicle design technology is highly IED resistant, weighs three times less than a current comparable up-armored vehicle, and consumes five times less fuel. This technology is rated TRL 7.

Technology to Aggressively Research Now for the Future:

Nuclear Energy. This technology, with many advances made over the past 40 years, should be explored for its potential for military application other than Navy ships. A moderate degree of research effort could produce nuclear-based technologies that enable employment of multiple-use portable and small form-fit transportable systems on the battlefield, the production of synthetic fuels aboard reactor designed ships to support ground forces in remote locations, applications that provide electrical propulsion energy to mobile combat systems, and, perhaps, combat systems powered by nuclear energy.

Conclusion

This research has hoped to provide insight into the need for the military to really energize efforts to solve a longstanding dependence on foreign fossil fuels by pursuing alternative energy and propulsion technologies. The technologies covered in this research show much promise. It is therefore only prudent and worthwhile for the US military, specifically the Army, to pursue now. In order to move forward aggressively in the manner necessary, the appropriate levels of funding must be in place and there must be a concerted effort to institute serious collaboration among key federal government, academia, and, maybe, foreign allied nations that would foster free and open exchange of ideas.

Last summer's energy crisis, like all previous energy crises, should have begun to seriously drive the United States toward, once and for all, actual energy independence. It seems as if history keeps repeating itself, and we have yet to really do something about it. Oil crises will, without a doubt, repeatedly continue to happen given the state of affairs in the world fossil fuel market. Every new president since the 1970s has promised to do something to eliminate our dependence on foreign oil. It certainly does not seem the case based on the findings in the paper. Our new recently elected President has also promised the same and has put initiatives in place to do so. Now is an excellent opportunity for the US Military to do something about foreign oil dependence given the aspirations of our new Commander-and-Chief. The Department of Defense must put together a comprehensive alternative energy strategy that complements the president's strategy for the nation—which would, once and for all, provide the energy independence our military has so desperately needed for many decades.

Appendix A: Peak Oil Theory

The theory was first advanced by Marion King Hubbert, an American geophysicist with Shell Oil, who created a method of modeling the production curve for an oil field. His theory said all oil fields follow the same bell-shaped production curve over their lifetimes. He based this on the observations that the amount of oil is finite and that the rate of discovery initially increases quickly, reaches a maximum, and then declines irreversibly. The factors that indicate the point of maximum production include discovery rates, production rates and cumulative production. However, these are difficult if not impossible to know with certainty. Early in the curve, production increases due to the discovery of new fields and the addition of production capacity. Post-peak production declines due to resource depletion. In 1956, Hubbert predicted US oil production would peak in approximately a decade, and fourteen years later it did. Today, in the lower 48 states the United States produces roughly half the oil it produced in 1970. However, Hubbert's predictions were incorrect with respect to ultimate US production. Improved technology and higher prices have resulted in far greater production since 1970 than predicted by Hubbert's model. Numerous studies have estimated the timing of global peak oil. In 2005, Robert Hirsch produced a study for the Atlantic Council called "Peaking of World Oil Production: Impacts, Mitigation, and Risk Management." In it, he compared twelve expert projections of when global peak oil would occur. They ranged between 2006 and 2025 or later.[103]

Appendix B: Blast Bucket Vehicle Design

The central hull of the main body is shaped like an egg with several distinct facets. This shape is found to be inherently rigid and will tend to deflect and shed projectiles and explosive blasts more readily than a flat-sided box. The underside is similarly shaped to provide protection against mines and the seemingly ubiquitous IEDs. The design also protects occupants from potential spinal compression or fracture injuries caused by violent upward acceleration from a blast or when the vehicle comes down on its side or roof. To counteract this problem, each seat is on shock-absorbing material that can compress a full 10 inches to reduce an 80-g shock by a factor of 10. The vehicle design incorporates easy-to-fasten shoulder belts that are designed to be worn loosely to provide freedom for weapon handling and other activities by the equipment-laden soldiers. These belts have integral airbags that inflate during an explosion to prevent the occupants from bouncing around the hard cabin.[104]

Appendix C: Opposed Piston Opposed Cylinder Engine Technology

The Opposed Piston Opposed Cylinder (OPOC) engine is a lightweight design developed under a Defense Advanced Research Projects Agency (DARPA) program. It is a two stroke scavenging type design with side-injection combustion and can be made to run on a number of fuels. It operates on one power stroke per each crank revolution per cylinder. The configuration is comprised of two cylinders per module. Each cylinder has two pistons moving in opposite directions. A crankshaft is between the two cylinders. The configuration of this design eliminates the conventional cylinder head and valve train components offering an efficient, compact and simple core engine structure. Modules can be connected together via a Modular Displacement Clutch, which synchronizes the modules for achieving even firing when both modules are functioning. With an optimized scavenging process, the special design features of the OPOC engine offer a significant step towards the potential of the two-stroke engine having double the power density of a four-stroke engine, while producing lower emissions and much better fuel efficiency.[105]

Appendix D: Description and Definition of Technology Readiness Levels

There are nine Technology Readiness Levels (TRL). The use of TRLs enables consistent, uniform, discussions of technical maturity across different types of technologies. Decision authorities will consider the recommended TRLs when assessing program risk. TRLs are a measure of technical maturity; the highest technical maturity level is 9. They do not discuss the probability of occurrence (i.e., the likelihood of attaining required maturity) or the impact of not achieving technology maturity.[106]

Table V. Technology Readiness Levels

Technology Readiness Level	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

ENDNOTES

[1] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[2] Sohbet Karbuz, The US Military Oil Consumption (Energy Bulletin, February 25, 2006).

[3] Defense Energy Support Center (DESC), Factbooks, (Fiscal Years 2002, 2003, 2004, 2005, 2006, & 2007).

[4] Sohbet Karbuz, The US Military Oil Consumption (Energy Bulletin, February 25, 2006).

[5] Sohbet Karbuz, The US Military Oil Consumption (Energy Bulletin, February 25, 2006).

[6] Sohbet Karbuz, The US Military Oil Consumption (Energy Bulletin, February 25, 2006).

[7] Sohbet Karbuz, The US Military Oil Consumption (Energy Bulletin, February 25, 2006).

[8] Sohbet Karbuz, The US Military Oil Consumption (Energy Bulletin, February 25, 2006).

[9] Dr. William Schneider, Jr., DoD Energy Strategy “More Fight – Less Fuel” (Report of the Defense Science Board Task Force, February 2008).

[10] Dr. William Schneider, Jr., DoD Energy Strategy “More Fight – Less Fuel” (Report of the Defense Science Board Task Force, February 2008).

[11] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[12] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[13] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[14] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[15] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[16] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[17] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[18] Byron W. King, Military Oil Usage Statistics (Peak Oil News, October 15, 2006).

[19] Dr. William Schneider, Jr., DoD Energy Strategy “More Fight – Less Fuel” (Report of the Defense Science Board Task Force, February 2008).

[20] U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) National Automotive Center (NAC), COL Fields’ Site visit and Face-to-Face Meeting with Mr. John Putrus, Mechanical Engineer, Hybrid Electric Vehicle Research, January 7, 2009.

[21] Dr. William Schneider, Jr., DoD Energy Strategy “More Fight – Less Fuel” (Report of the Defense Science Board Task Force, February 2008).

[22] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[23] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[24] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[25] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[26] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[27] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[28] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[29] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[30] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[31] Department of Energy website, December 2008 Crude Oil and Petroleum Import Highlights, February 27, 2009

[32] Department of Energy website, December 2008 Crude Oil and Petroleum Import Highlights, February 27, 2009

[33] Defense Energy Support Center (DESC), Factbook, Fiscal Years 2006.

[34] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[35] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[36] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008)..

[37] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[38] Naval Research Advisory Committee (NRAC), Report on Future Fuels (April 2006).

[39] Naval Research Advisory Committee (NRAC), Report on Future Fuels (April 2006).

[40] Naval Research Advisory Committee (NRAC), Report on Future Fuels (April 2006).

[41] Naval Research Advisory Committee (NRAC), Report on Future Fuels (April 2006).

[42]Hydrogen use in Internal Combustion Engines (College of the Desert, Module 3, December 2001).

[43] BMW Hydrogen 7 (Various industry sources at Wikipedia.org, , February 13, 2009).

[44] Media Ford, Ford launches production of Hydrogen ICE's for delivery to customers (Ford Motor Company website, July 17, 2006).

[45] Department of Energy, Hydrogen Internal Combustion Engine Technology (DoE Website, July 2, 2008).

[46] Department of Energy, Hydrogen Internal Combustion Engine Technology (DoE Website, July 2, 2008).

[47] Department of Energy, FY2008 Annual Performance Report (DoE Website, January 22, 2009).

[48] Department of Energy, Hydrogen Internal Combustion Engine Technology (DoE Website, July 2, 2008).

[49] TARDEC is the Nation's laboratory for advanced military automotive technology.

[50] COL Fields' Site visit and Face-to-Face Meeting with Ms Heather McKee, Mechanical Engineer, Power & Energy Technologies (U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) National Automotive Center (NAC), January 7, 2009).

[51] Department of Energy, Energy Efficiency and Renewable Energy (Hydrogen, Fuel Cells & Infrastructure Technologies Program, February 24, 2009).

[52] Defense Advanced Research Projects Agency, BioFuels, (DARPA Website, Strategy Technology Office).

[53] COL Fields' Face-to-Face Meeting and PowerPoint presentation, TARDEC Assured Fuels Initiative, with Mr. Eric Sattler, Project Engineer (U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) National Automotive Center (NAC), January 7, 2009).

[54] Business-Week, Reviews: 2009 Honda FCX Clarity (Business-Week Website, April 9, 2008).

[55] Fuel Cell Works, Honda Introduces City of Las Vegas as Next Fuel Cell Customer (Fuel Cell Works Website, February 3, 2005).

[56] Alternative Energy News, New Hydrogen Purification Method (Alternative Energy News Website, March 5, 2009).

[57] Michael Blain and Ghassan Khalil, TARDEC's Hybrid Electric Program (U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) Quarterly Magazine, Spring 2008 issue).

[58] Environmental Protection Agency, Hydraulic Hybrid Research, (Office of Transportation and Air Quality (OTAQ) Website, July 8, 2008); and COL Fields' Site Visit and Meeting with Mr. John Kargul, OTAQ's Director of Technology Transfer (January 8, 2009).

[59] Environmental Protection Agency, Hydraulic Hybrid Research, (Office of Transportation and Air Quality (OTAQ) Website, July 8, 2008); and COL Fields' Site Visit and Meeting with Mr. John Kargul, OTAQ's Director of Technology Transfer (January 8, 2009).

[60] Environmental Protection Agency, Hydraulic Hybrid Research, (Office of Transportation and Air Quality (OTAQ) Website, July 8, 2008); and COL Fields' Site Visit and Meeting with Mr. John Kargul, OTAQ's Director of Technology Transfer (January 8, 2009).

[61] Rexroth Bosch Group Presentation on Hydraulic Hybrid Vehicle Technologies (Rexroth Bosch Website, September 9, 2008).

[62] Joseph Ogando, Senior Editor, Hydraulic Powertrains Propel These Hybrid Trucks (Design News website, July 16, 2007).

[63] Rexroth Bosch Group Presentation on Hydraulic Hybrid Vehicle Technologies (Rexroth Bosch Website, September 9, 2008).

[64] Environmental Protection Agency, Hydraulic Hybrid Research, (Office of Transportation and Air Quality (OTAQ) Website, July 8, 2008); and COL Fields' Site Visit and Meeting with Mr. John Kargul, OTAQ's Director of Technology Transfer (January 8, 2009).

[65] Joseph Ogando, Senior Editor, Hydraulic Powertrains Propel These Hybrid Trucks (Design News website, July 16, 2007).

[66] TARDEC NAC Website

[67] Heather McKee, Mechanical Engineer, What Can NAC Do for Brown? Drive Military's Use of Hyrdraulic-Hybrid Technology (U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) Quarterly Magazine, October-December 2008 issue); and COL Fields' Site Visit and Meeting with Ms. Heather McKee, Mechanical Engineer, Power & Energy Technologies, January 8, 2009.

[68] Eugene Hsiao and Christopher Richter, Electric Vehicles – Special Report on Lithium Nirvana – Powering the Car of Tomorrow (CLSA Asia-Pacific Markets – June 2, 2008).

[69] Eugene Hsiao and Christopher Richter, Electric Vehicles – Special Report on Lithium Nirvana – Powering the Car of Tomorrow (CLSA Asia-Pacific Markets – June 2, 2008).

[70] COL Fields' Face-to-Face Meeting with Masters Rogelio Sullivan, Group Leader, and Jerry Gibbs, Materials Engineer, Vehicles Technologies Program (Department of Energy, January 9, 2009).

[71] Department of Energy, Energy Storage (Energy Efficiency and Renewable Energy, Vehicle Technologies Program website, January 8, 2009).

[72] Sonya Gargies, Electrical Engineer, Energy Storage Team Leader, Energy Storage Manufacturing – High-Power, High-Energy Density Lithium-Ion Batteries (U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) Quarterly Magazine, Spring 2008 issue).

[73] COL Fields' Face-to-Face Meeting with Ms Sonya Gargies, Electrical Engineer, Energy Storage Team Leader (TARDEC, January 7, 2009).

[74] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[75] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[76] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[77] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[78] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[79] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[80] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[81] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[82] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[83] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[84] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[85] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[86] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[87] Csaba Csere, The Pentagon Enlists the Racing Mind-Set – Column (Car and Drive website, February 2006).

[88] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008); and Georgia Tech Research News (Website, September 12, 2005).

[89] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[90] David Crane, Ultra AP and Ultra 3T Concept/Experimental Armored Vehicles for U.S. Infantry (Defense Review Website, June 7, 2008).

[91] David Crane, Ultra AP and Ultra 3T Concept/Experimental Armored Vehicles for U.S. Infantry (Defense Review Website, June 7, 2008).

[92] David Crane, Ultra AP and Ultra 3T Concept/Experimental Armored Vehicles for U.S. Infantry (Defense Review Website, June 7, 2008).

[93] Dr. William Schneider, Jr., DoD Energy Strategy "More Fight – Less Fuel" (Report of the Defense Science Board Task Force, February 2008).

[94] Dr. William Schneider, Jr., DoD Energy Strategy “More Fight – Less Fuel” (Report of the Defense Science Board Task Force, February 2008).

[95] Lawrence H. Suid, The Army’s Nuclear Power Program – The Evolution of a Support Agency (Greenwood Press, 1990).

[96] Ford Nucleon (Various industry sources at Wikipedia.org, February 27, 2009).

[97] Bruce Gain, Road Testing BMW's Hydrogen 7 (Wired website, November 13, 2006).

[98] How the Recovery Bill Could Benefit Fuel Cells (FuelCellInsider.org, March 26, 2009).

[99] How the Recovery Bill Could Benefit Fuel Cells (FuelCellInsider.org, March 26, 2009).

[100]Supporting Data FY 2009 Budget Estimate for Research, Development, Test And Evaluation, Army Appropriation, Budget Activities 1, 2, and 3 (Defense Technical Information Center, February 2008)

[101] Heather McKee, TARDEC NAC Mechanical Engineer, Heather McKee’s Contracting Actions (Excel Spreadsheet, December 9, 2008) .

[102]Supporting Data FY 2009 Budget Estimate for Research, Development, Test And Evaluation, Army Appropriation, Budget Activities 1, 2, and 3 (Defense Technical Information Center, February 2008) .

[103] Dr. William Schneider, Jr., DoD Energy Strategy “More Fight – Less Fuel” (Report of the Defense Science Board Task Force, February 2008).

[104] Csaba Csere, The Pentagon Enlists the Racing Mind-Set – Column (Car and Drive website, February 2006).

[105] Curtis Ellzey, Opposed Piston Opposed Cylinder Engine (Engineering TV Website, July 1, 2008; and Advanced Propulsion Technologies (Propulsion Tech Website).

[106] Defense Acquisition Guidebook (Defense Acquisition University Website, July 24, 2006).